Atomic and Laser Spectroscopy

MODERN PHYSICS
SH1009

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Part I: Calibration

In this part the aim was to find a calibration equation in order to find a relation between the channels and the wavelengths of the light detected by the spectrometer, so that we could use this relation to find the wavelength in part two (atomic spectroscopy) and part tree (laser spectroscopy). In order to calculate a calibration equation a small exercise was needed. The results were going to be plotted and a trend line calculated by a program (exel in our case) gave the searched equation.
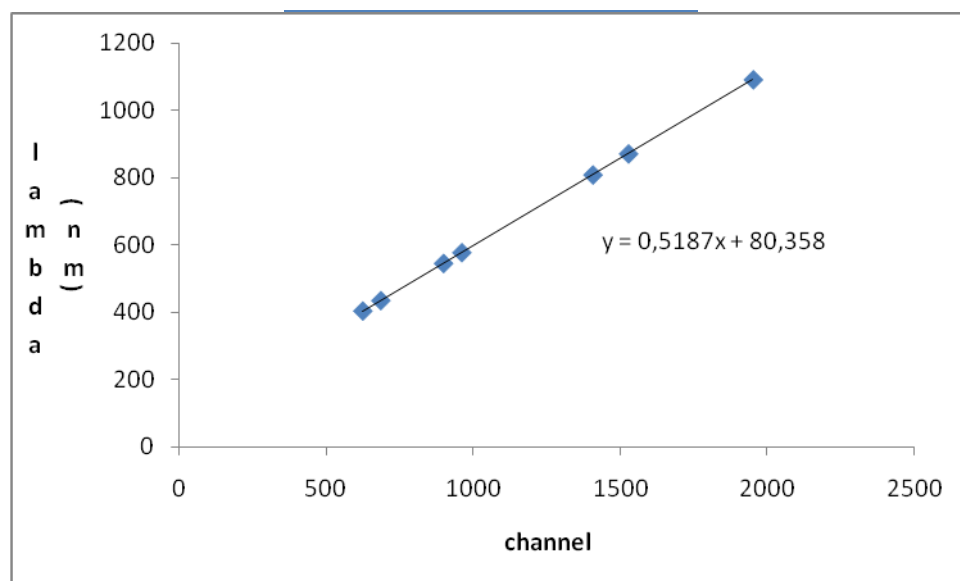
Experimentation

The light of the roof lamp was directed with a mirror through a filter into the spectrometer, which sent data to the computer. A graph was gotten and values were written down.
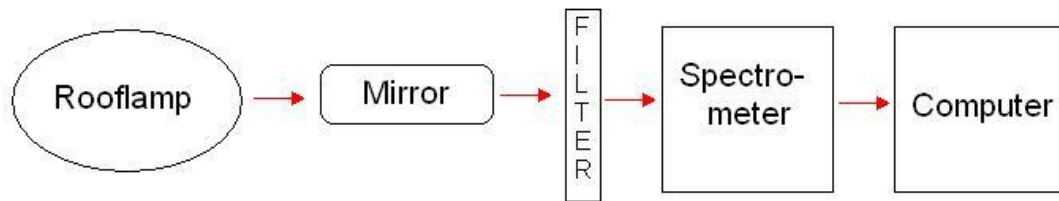
The 4 filters used had different wavelength. According to Bragg's law we got one to two peaks for each filter. Each peak corresponds to maximum when the light is diffracted. Plotting wavelength (Lambda) as function of the intensity (Channel) the following equation is gotten:

| Channel	Lambda (nm)	Exposure (s)
624,3	404,7	0,1
685,4	435,8	0,5
898,4	546,1	0,03
960,4	578,2	0,1
1405,5	809,4	0,1
1526,3	871,6	0,5
1950,1	1092,2	0,03

$y = 0{,}5187x + 80{,}358$

Part II: Atomic spectroscopy

The aim of part II was to find the Rydberg constant for hydrogen in the following equation:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f{}^2} - \frac{1}{n_i{}^2}\right)$$

Experimentation

The light of an hydrogen lamp was directed into the spectrometer, and transferred to the computer, as it is show in the following diagram.
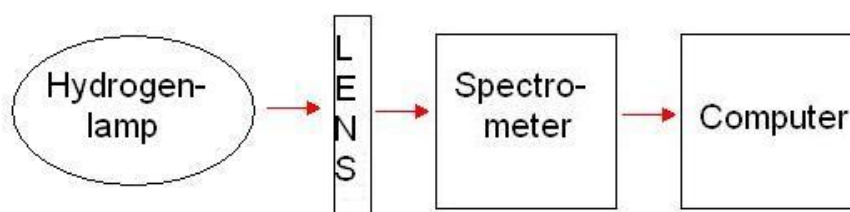
In order to find the Rydberg constant we had to find the wavelengths for the incoming light, reading the channels from the computer screen and using the equation found in part I. We studied the Balmer series of hydrogen (n_f=2). We found peaks corresponding to the first four energy transitions of the Balmer series ($H_\alpha, H_\beta, H_\gamma, H_\delta$)
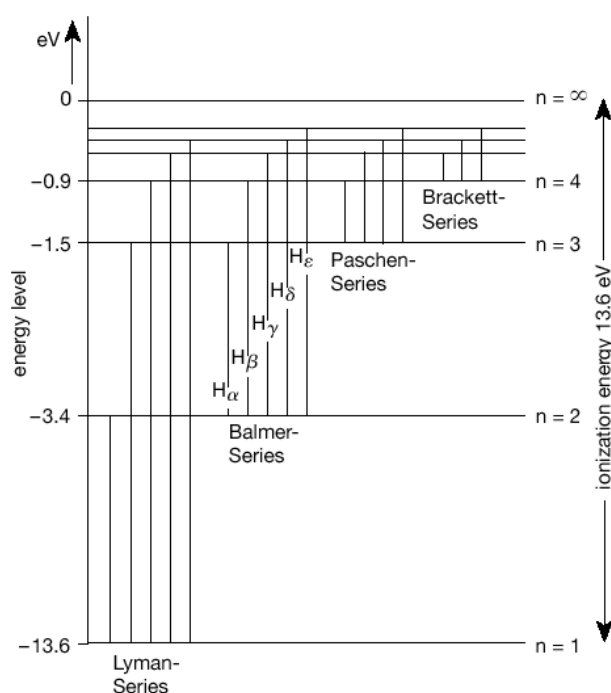
In the following table n_f is the final state in the transition and n_i the initial state.

ni	Channel	lambda(nm)	R (1/nm)
3	1112,4	656,55	$1{,}097 \cdot 10^{-2}$
4	982,2	589,10	$0{,}905 \cdot 10^{-2}$
5	783,4	486,13	$0{,}980 \cdot 10^{-2}$
6	649,1	416,61	$1{,}080 \cdot 10^{-2}$

Which gives us an average for the Rydberg constant, R_{avg}=1,080*10^7 m^{-1}. This value is very close to

the theoretical value, which is $1{,}097 \cdot 10^{-7}$ m^{-1}.

Part III: Laser spectroscopy

In this third part the aim is to determine the Morse potential function for a molecule of 2 atoms of iodine (I_2). In order to find it, we studied the spectrum of iodine molecules excited by HeNe 543.5 nm laser light. Using the same calibration as previously, we found a correspondence between the wavelengths of the light received by the computer, and the channels seen on the computer screen.

We then tried to find to which vibrational quantum number (v) the energy shown by those wavelengths corresponded to, so that we could use relationships to find out the values of the constants in the Morse potential function, such as w_e and D_e (dissociation energy needed to break the molecule). The wave number is defined as:

$$\sigma = \frac{1}{\lambda}$$

To get the Morse potential function it is necessary to firstly get an equation by plotting Δσ as a function of the vibrational level.

Experimentation

The light of a HeNe laser was directed into a gas of iodine molecules and excited those molecules that then produced photons. This light passed then through a lens and was sent to the spectrometer, and analyzed by the computer, getting channel measurements.
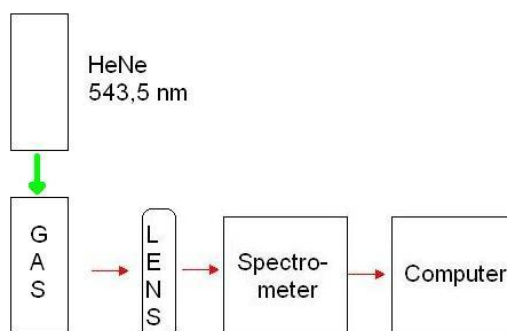
We got following values corresponding to the peaks of the curve we got on the screen. With help of the calibration equation we calculate the wavelength and the sigma values:

Channel	Lambda (nm)	sigma (1/nm)
855,2	523,3	$1,910 \cdot 10^{-3}$
894,2	543,5	$1,840 \cdot 10^{-3}$
1012,2	604,7	$1,654 \cdot 10^{-3}$
1064,2	631,6	$1,583 \cdot 10^{-3}$
1231,2	718,1	$1,393 \cdot 10^{-3}$

We know from the theory that:

$$\Delta\sigma = \omega_e - 2\omega_e x_e(v+1)$$

Plotting $\Delta\sigma$ as a function of the vibrational level we get:
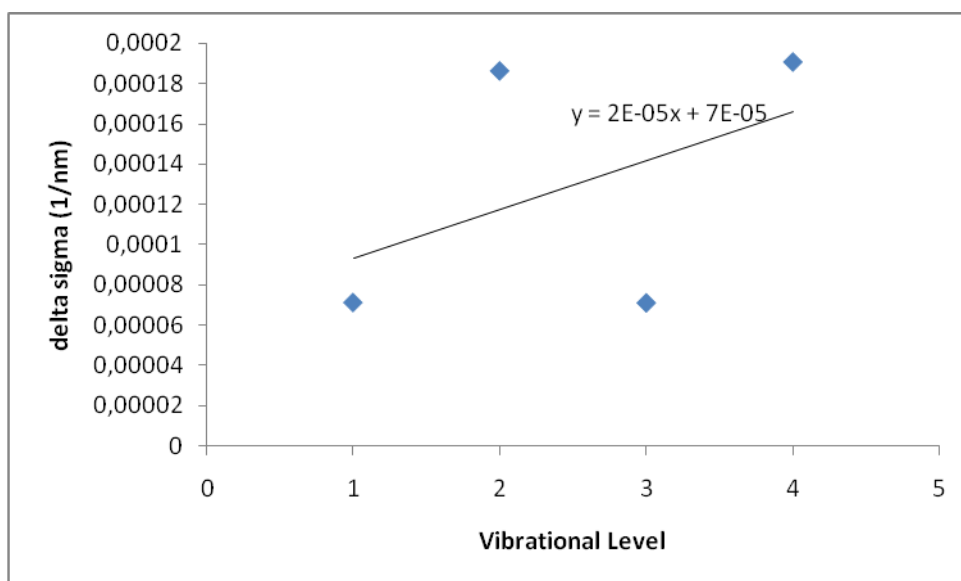
Comparing the trend line's equation with $\Delta\sigma = \omega_e - 2\omega_e x_e x$ we find that: $\omega_e = 7 \cdot 10^{-5} nm^{-1}$ and? $2\omega_e x_e = 2 \cdot 10^{-5} nm^{-1}$.

The Morse potential function is $V(r) = D_e \cdot [1 - e^{a(r_e - r)}]^2$. Now with some relations we calculate the constants.

$$D_e = \frac{\omega_e^2}{4 \cdot \omega_e x_e} = 1,225 \cdot 10^{-4} \text{ nm}^{-1}$$

According to the NIST Chemistry WebBook we know that $B_e = 0.03737 \, cm^{-1}$.

$$B_e = \frac{h}{8\pi^2 c \mu r_e{}^2} \rightarrow r_e = \sqrt{\frac{h}{8\pi^2 c \mu B_e}}$$

Where h is the plank constant, c is the speed of light, μ is the reduced mass. The reduced mass of I$_2$ is

$$\mu = \frac{m_1 \cdot m_2}{m_1 + m_2} = \{m_1 = m_2 = m\} = \frac{m}{2}$$

$$m_{I_2} = 2 \cdot m \rightarrow m = \frac{m_{I_2}}{2}$$

Where $m_{I_2} = 253.80894\,u$

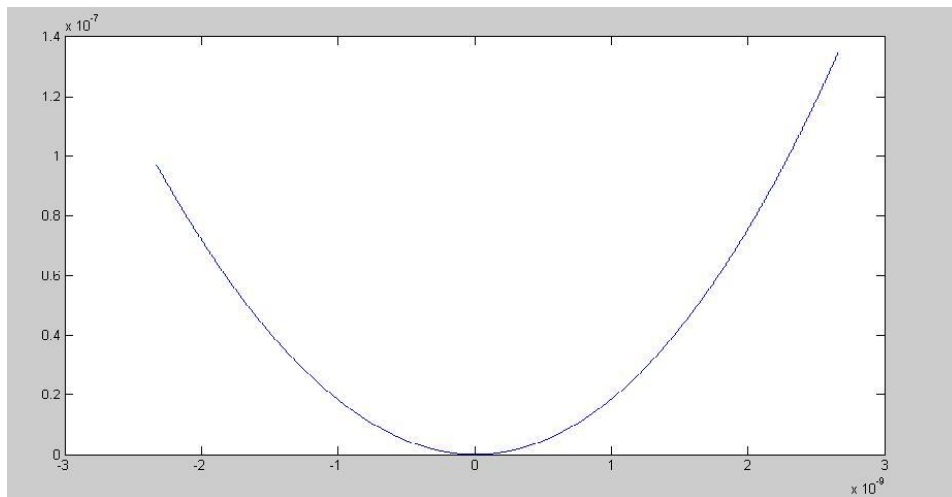$$r_e = \sqrt{\frac{h}{2\pi^2 c m_{I_2} u B_e}} = 2{,}667\ nm$$

Now we calculate the value of 'a' with the relation:

$$\omega_e x_e = \frac{h a^2}{16\pi^2 c \mu} \rightarrow a = 2\pi \sqrt{\frac{\omega_e x_e c m_{I_2} u}{h}} = 12268373{,}91\ m^{-0{,}5}$$

So finally

$$\underline{V(r) = 1{,}225 \cdot 10^{-4} \cdot \left[1 - e^{12268373{,}91\,(2{,}667 \cdot 10^{-9} - r)}\right]^2}$$

Which is the Morse potential equation!

[This is the plot of the gotten Morse's Potential equation above, i.e. V(r)]

Sources of error

The environment of the lab affected our data values, which may lead to wrong calculations from now on. The experiment set up could not allow us to capture the light properly, and the light was therefore too weak to be detected by the spectrometer. Our data are therefore not reliable, and might be interpreted as just noise.

When it comes to laserspectroscopy, the values that we found for the vibrational level to delta sigma are far from corresponding to a straight line, which is due to the fact that the light actually received was not just the light emitted by iodine. It mainly contained noise. Our numerical results are therefore not reliable.